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BIOCOMPOSITES AND BIOBLENDS BASED ON ENGINEERING THERMOPLASTICS FOR AUTOMOTIVE APPLICATIONS

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Summary: *This paper presents viable solutions concerning the formulation, processing and performance of biocomposites and bioblends based on engineering thermoplastics for application in automotive interiors. Polyamide (PA6) and acrylonitrile-butadiene-styrene (ABS) were formulated to produce biocomposites containing up to 40 wt.% cellulosic fibers. Bioblends of PA6 and ABS containing up to 30 wt.% polylactide (PLA) were obtained as well. Finally, different biocomposites were compounded based on PA6 / PLA and ABS / PLA blends containing cellulosic fibers. These biocomposites and bioblends were evaluated in terms of morphology, mechanical and thermal properties, as well as for cost and weight reductions. The tensile strength, tensile modulus, and heat deflection temperature presented at least equivalent values as neat PA6, neat ABS and commercial grades currently used in the fabrication of automotive interior parts. Furthermore, foamed samples obtained from these biocomposites through injection foaming process presented similar properties as unfoamed and commercial grades while being up to 10 wt.% lighter, 37 % less expensive, and 40 wt.% greener.*

1 INTRODUCTION

Automotive industry, as all the other industries, growingly faces toward the use of environmental friendly materials and processings for the manufacturing of lighter, lower-cost and greener materials. The driving forces for the greener implementations are to decrease the part weight, the material cost, the fuel consumption and to increase the use of eco-friendlier materials and processing methods while maintaining the safety of the cars. Given these major needs, the automotive industry looks at the replacements of heavy metals by lighter and less expensive polymer parts or / and by lower-cost polymer biocomposites containing bio-sourced materials. Thermoplastic bioblends and biocomposites seem to have high potentials to act as partial or complete substitutes of petroleum-based thermoplastics and composites [1].

About 180 kg of thermoplastics are used in one car, i.e. 12 % from the car weight and 50 % from the car volume. Most of these thermoplastics are actually used as glass fibers (GF) reinforced composites or mineral filled compounds [1-3]. Amongst these thermoplastics, the PP (around 80 kg), the PA6 / PA66 (around 20 kg) and the ABS / ABS alloys (around 15 kg) are the most employed in the fabrication of automotive interior parts.

The polyamides are used in engine shrouds, engine covers, gearshifts, front-end grills, oil pan modules, manifolds, funs, and other parts. Typically, the nylons are formulated using GF or mineral fillers, composites and compounds that are heavy and quite expensive. It was shown in the literature that the replacement of a part of PA6 or PA66 matrix with cellulosic fibers could increase the mechanical properties compared to the neat matrix [4-9]. It looks like the cellulosic fibers have a reinforcement potential in those matrix and offer many possibilities for the automotive applications. On the other hand, the substitution of a part of nylon matrix by polylactic acid biopolymer (PLA) seems to have as result the preservation or a slightly increase in mechanical properties when adequate coupling agents are used [7, 10, 11].

ABS filled with minerals, ABS reinforced with GF, and ABS / PC alloys are utilized in the fabrication of overhead consoles, grills, spoilers, B / C pillars, fascia and instrument panels, door and setting assemblies, dashboards etc. Scarce published studies exist on biocomposites based on ABS / cellulosics or bioblends made from ABS / biopolymers designated to be used as biomaterials for automotive interior applications [7, 12]. With the purpose to support automotive industry's green vision, this paper substantiates that the use of PA6 and ABS for automotive interior applications should pass through the following strategies:

- Replacement of thermoplastic polymers filled with minerals or reinforced with GF by biocomposite containing cellulosic fibers, as way to decrease weight and cost.
- Utilization of the injection foaming process, as additional way to decrease the weight and cost.
- Substitution of a part of the engineering thermoplastic matrix by a bioplastic, as way to increase the renewable content.
- Application of combinations of those strategies.

This paper discloses the results of applying the before mentioned strategies to the fabrication of PA6 and ABS bioblends and biocomposites designated to be used in cars. Sizeable cost and weight reductions are achieved using these biomaterials in appropriate fabrication processes. When cellulosic materials replace up to 40 wt.% of petroleum-based thermoplastics, around 37 % cost reduction is reached. Up to 10 % lighter parts can be produced by adapting the injection foaming process to PA6 and ABS biocomposites behavior. Combinations of engineering thermoplastics with cellulosic fibers and PLA further allow the fabrication of biomaterials with up to 40 wt.% renewable content while preserving significant cost and weight reductions. These environmental friendly biomaterials present equivalent performances compared to thermoplastic compounds and composites currently used in automotive applications and should be considered as eco-solutions in the manufacturing of greener automotive interior parts.

2 EXPERIMENTAL PART

2.1 Materials

The PA6 used in this work was an injection molding grade from BASF, the Ultramid B27. Two PA6 automotive commercial grades were used as references:

- A high impact grade of PA6 filled with 30 wt.% minerals, Ultramid B3M6 from BASF.

- A PA6 reinforced with 30 wt.% GF, Ultramid B3WG from BASF.

The ABS used in this work was Lustran Elite HH 1827 from Ineos, an injection-molding grade for high-heat automotive applications. The properties of two ABS automotive commercial grades were used as references:

- A talc filled grade (talc concentration not disclosed by manufacturer), Stat-Loy AX06484 from Sabic.
- A 30% GF reinforced ABS, AF306 from Sabic.

PLA 8302D, an amorphous grade from Nature Works, was selected as the bio-based phase for the production of PA6/PLA and ABS/PLA bioblends.

The cellulosic fibers used to fabricate the biocomposites were:

- Short flax fibers supplied by Schweitzer Mauduit Canada,
- Thermo-mechanical pulp (TMP) supplied by Papier Masson Canada / White Birch,
- Wood fibers (WoodForce - WF) in form of dices supplied by Sonae Industria.

The two first types of cellulosic fibers have very low bulk densities and were densified to assure a consistent flow rate in the compounding line. The cellulosic fiber concentrations used to produce the biocomposites were 20 wt.% and 40 wt.%. GF of 6.5 mm in length were also used to produce hybrid composites. Appropriate concentrations of specific coupling agents were considered in each thermoplastic / cellulosic, thermoplastic / PLA bioblend and thermoplastic / PLA / cellulosic combination. All the raw materials were dried before extrusion for 24 hours at appropriate temperatures.

2.2 Processing

2.2.1 Extrusion Process

The extrusion line operated to compound the bioblends and the biocomposites was a Leistritz 34 mm co-rotating twin-screw extruder with 12 mixing zones and L/D ratio of 40. Two feeding locations were available: the polymers and additives were fed in the first zone while cellulosic fibers were incorporated at mid-extruder. The used screw configuration was specially designed in our laboratory with the purpose to avoid as much as possible the attrition of the fibers during compounding while preserving a good fiber dispersion and distribution. At the extrusion line exit, a capillary die of 2 mm in diameter was used. The temperature profiles used to compound the bioblends and the biocomposites were constant all along the extrusion line, i.e. 240 °C for PA6 biomaterials and 210 °C for ABS biomaterials.

2.2.2 Injection molding and injection foaming

All compounded bioblends and biocomposites pellets were first dried for 24 hours at appropriate temperatures and then injection molded using a 34 tons BOY press. The injection barrel and mold temperatures were adapted for each biomaterial. Standard specimens were molded according to ASTM D638 and ASTM D256 for tensile and Izod impact properties evaluation, respectively. To foam the bioblends and the biocomposites in injection molding, 1 wt.% of Hydrocerol 1514 from Clariant was used as chemical blowing agent (CBA).

2.3 Characterization

2.3.1 Morphology

Scanning electron microscopy (SEM) was done on impact-fractured biocomposite surfaces. A coating of gold / palladium alloy was applied on the specimens prior to the observation. A JEOL JSM-6100 SEM at a voltage of 10 kV was used.

2.3.2 Mechanical Properties

The tensile testing was carried out according to ASTM D638 at a velocity of 5 mm/min on standard type I dog-bone shaped samples. The tensile modulus (TM) and the tensile strength (TS) were evaluated. A video extensometer was used to determine the elastic modulus. The Izod impact strength (IS) was evaluated according to ASTM D256 using notched specimens and a 2 kg hummer. All reported values are the average of at least five tests.

2.3.3 Heat Deflection Temperature

The heat deflection temperature (HDT) was measured using the Instron Ceast HDT-3-Vicat device. The ASTM D648 was applied as follows: a bar of rectangular cross section was tested in the edgewise position as a simple beam with the load of 0.455 MPa applied at its center. The specimen was immersed under load in a heat-transfer medium which temperature rose by 2 °C/min. The HDT under flexural load was recorded as the temperature of the medium at which the test bars deflected by 0.25 mm.

3 RESULTS AND DISCUSSIONS

3.1 Morphology of PA6 and ABS biocomposites

Figure 1 shows the morphology of transversal fractured surfaces of biocomposite specimens resulted from the Izod-impact testing. The micrographs correspond to PA6 biocomposites with 20 wt.% flax and ABS biocomposites with 20 wt.% WF. These micrographs are shown at low magnification (x 100, left and middle columns) for formulations without and with coupling agents and, at higher magnification (x 500, right column), for the formulations with coupling agents. All the other PA6 and ABS biocomposites obtained in this work presented similar morphological aspects and, for simplicity, were not all presented here. The micrographs exhibit uniformly distributed cellulosic fibers within the corresponding matrices. This proves an excellent dispersion and distribution of cellulosic fiber pellets in the polymer matrix due to the dynamics created by the screw configuration specially designed for these experiments. The fractured surfaces of the biocomposites without additives (left column) display poor interfacial adhesions as observed from the cellulosic fiber pull-out. The fractures were produced at the cellulosic fiber / matrix interfaces and this is closely related with poor adhesion due to the absence of the coupling agents. The fractured surfaces show less cellulosic fiber pull-out (middle and right columns) when coupling agents were incorporated in the biocomposite formulations. It can be observed that, in this case, the cracks were propagated predominantly through the polymer matrix and through cellulosic fibers themselves (right column) because the fiber-matrix strength was enhanced. These observations confirmed the heightening of polymers / cellulosic fibers adhesion in the PA6 / flax and ABS / WF compatibilized systems.

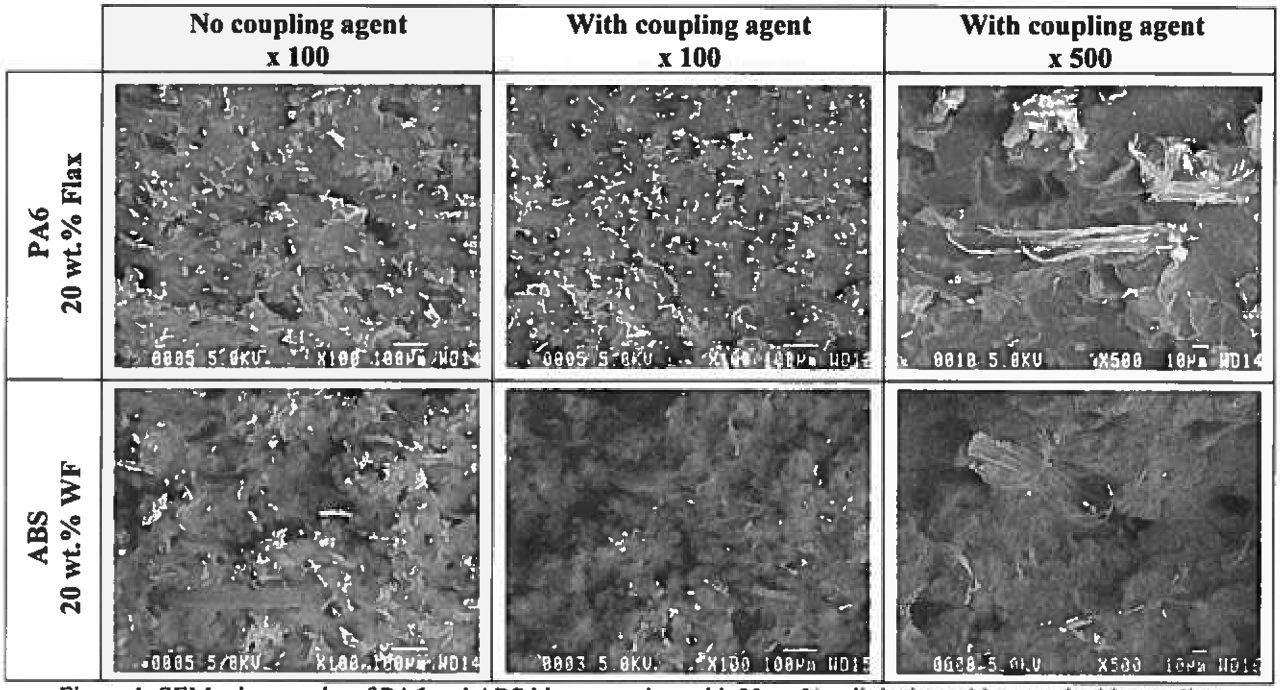

Figure 1. SEM micrographs of PA6 and ABS biocomposites with 20 wt.% cellulosics, without and with coupling agents.

3.2 Lower-cost biocomposites based on PA6 and ABS

Replacement of a part of thermoplastic matrix by cellulosic fibers

Figure 2 reveals a comparison of mechanical properties, relative costs and density of neat PA6, PA6 biocomposites obtained in this work containing 20 and 40 wt.% WF, and the commercial grade of PA6 / 30 wt.% minerals. The tensile strengths of PA6 / 20 wt.% WF and PA6 / 40 wt.% WF were increased by 14 % and 27 % respectively comparing with neat PA6 and are comparable to the tensile strength of the commercial PA6 / 30 wt.% minerals. Tensile modulus of PA6 / 20 wt.% WF disclosed similar value as the commercial grade while PA6 / 40 wt.% WF presented a tensile strength up to 30 % higher. In terms of Izod impact strength, the biocomposites presented, as expected, similar values as the neat PA6 but lower than the one of PA6 commercial grade. This commercial grade is already formulated for impact applications while PA6 biocomposites from this work were basic formulations with no content of impact additives as modifiers. Therefore, these basic formulations could be improved for high impact applications by adding specific impact additives in adequate concentrations. The densities of the developed biocomposites, 1.20-1.25 g/cm^3, were between the neat PA6 one (1.15 g/cm^3) and the PA6 / 30 wt.% minerals commercial grade (1.36 g/cm^3).

The market prices of neat PA6, of PA6 / 30 wt.% minerals commercial grade, and of the three types of cellulosic fibers (Table 1a) were considered in the evaluation of the relative material costs of PA6 biocomposites studied in this work (Table 1b). As a function of cellulosic type used, the PA6 biocomposites with 20 wt.% cellulosic fibers presented about 14 - 19 % cost reductions and the PA6 biocomposites with 40 wt.% cellulosic fibers present cost reductions in the range 28 - 37 % respectively. The PA6 biocomposites presented an important cost reduction, in comparison to polyolefin biocomposites, because the important gap existing between the price of PA6 and the prices of the cellulosics. Therefore, is important to note that the PA6 biocomposites obtained in this work presented lower costs at equivalent properties compared to the commercial PA6 / 30% minerals grade.

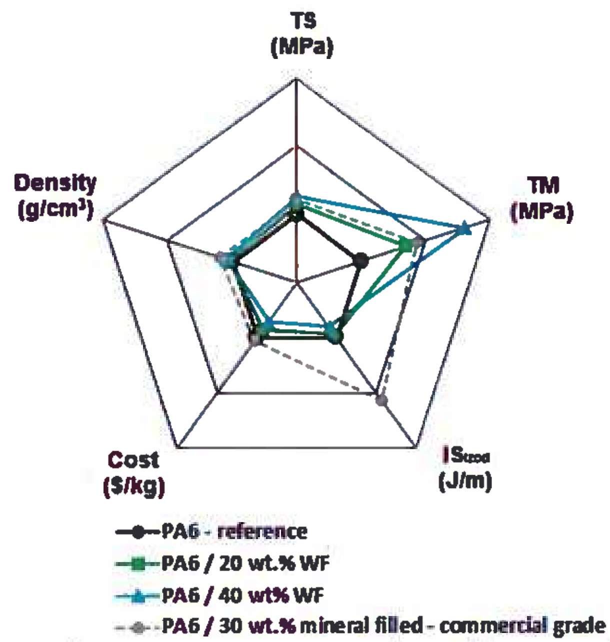

Figure 2. Comparison of properties and cost of: neat PA6, PA6 / 20wt.% and 40 wt.% WF and the commercial grade PA6 / 30 wt.% minerals.

Virgin PA6 (CAD/kg)	PA6 / 30 wt.% minerals (CAD/kg)	Flax CAD/kg)	TMP (CAD/kg)	WF (CAD/kg)
4.9	5.3	1.0	0.3	1.5

Table 1a. Approximate market prices of raw materials.

	Cellulosic contents			
	20 wt.%		40 wt.%	
	Cost (CAD/kg)	Cost reduction (%)	Cost (CAD/kg)	Cost reduction (%)
PA6 / Flax	4.2	16.0	3.4	32.0
PA6 / TMP	4.0	19.0	3.1	37.6
PA6 / WF	4.3	14.0	3.6	27.8

Table 1b. Calculated costs and cost reductions of obtained PA6 biocomposites.

Figure 3 presents a comparison of mechanical properties, HDT and density of neat ABS, ABS biocomposites containing 20 and 40 wt.% WF developed in this work, commercial grade ABS / talc and commercial grade ABS / 30 wt.% GF. The tensile strengths of the ABS / 20 wt.% WF and ABS / 40 wt.% WF were higher than neat ABS and the two ABS commercial grades.

The tensile modulus of ABS / 20 wt.% WF was twofold higher than ABS and ABS / talc commercial grade and the tensile modulus of ABS / 40 wt.% WF was very similar to ABS / 30 wt. % GF. In terms of elongation at break, the biocomposites present a loss of elastic properties as usually expected at the incorporation of cellulosic fibers. The densities of the ABS biocomposites, 1.11 and 1.17 g/cm^3 respectively, were very similar to ABS (1.05 g/cm^3) and are 15-20% lower than that of ABS commercial automotive grades (1.39 and 1.29 g/cm^3 respectively).

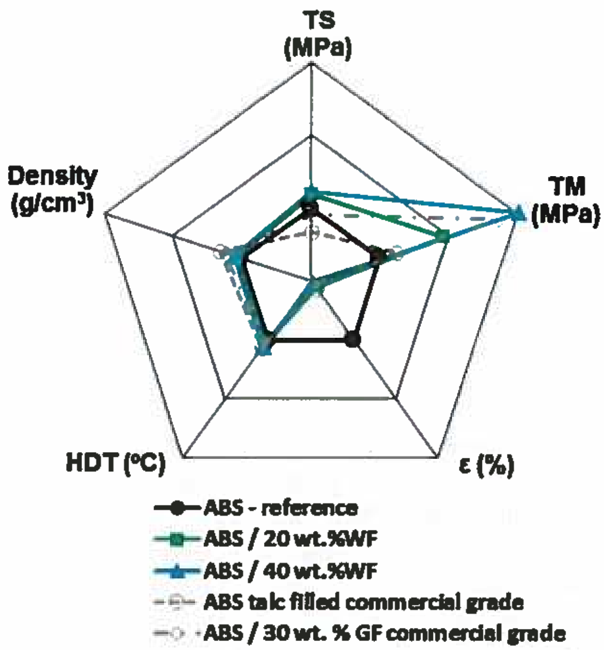

Figure 3. Comparison of mechanical and thermal properties of: reference ABS, ABS / 20 wt.% and 40 wt.% WF and the ABS commercial grades

Virgin ABS (CAD/kg)	ABS / 30 wt.% talc (CAD/kg)	Flax (CAD/kg)	TMP (CAD/kg)	WF (CAD/kg)
3.6	3.6	1.0	0.3	1.5

Table 2a. Market prices of raw materials

	Cellulosic contents			
	20 wt.%		40 wt.%	
	Cost (CAD/kg)	Cost reduction (%)	Cost (CAD/kg)	Cost reduction (%)
ABS / Flax	3.1	14.5	2.6	29.0
ABS / TMP	2.9	18.3	2.3	36.7
ABS / WF	3.2	11.6	2.8	23.2

Table 2b. Calculated costs of obtained ABS biocomposites

As in PA6 case, the actual market prices of neat ABS and of the three types of cellulosic fibers (Table 2a) were used in the evaluation of the relative costs of ABS biocomposites produced in this work. As shown in Table 2b, the ABS biocomposites with 20 wt.% cellulosic fibers presented up to 18.3 % cost reductions and the ABS biocomposites with 40 wt.% cellulosic fibers presented a cost reduction up to 36.7 % respectively. Consequently, the ABS biocomposites presented here could have lower costs at higher tensile properties compared to ABS commercial grades. Nonetheless, it has to be pointed out that our ABS biocomposite materials necessitate further upgrading in terms of impact response by adding impact modifiers in their formulations.

3.3 Lightweight biocomposites based on PA6 and ABS

In our experimental trials, lighter biocomposites were obtained using two strategies:

- Formulation strategy: replacement of GF as reinforcements by cellulosic fibers.
- Processing strategy: foaming of biocomposites in injection molding using chemical blowing agents (CBAs).

Formulation strategy: lightweighting through replacement of GF by cellulosic fibers

The density of cellulosic fibers varies from 1.3 to 1.5 g/cm^3 depending on fiber type and fiber source while the density of GF is almost two times higher, i.e. of 2.55-2.6 g/cm^3. On the other hand, the price of cellulosic fibers which varies from 0.3 to 1.5 $/kg, is lower than the price of GF which is about 3-4 $/kg depending on grade. Replacing totally or partially the glass fibers by cellulosic fibers is a weight / cost dual strategy that encourages the replacement of GF composites by cellulosic biocomposites with obviously lower weight and cost. In this work, biocomposites with 20 wt.% and 40 wt.% cellulosic fibers were obtained using PA6 and ABS as matrixes. For evaluation purposes, hybrids containing 20 wt.% WF / 20 wt.% GF were also compounded based on the two engineering thermoplastics.

As presented in the Figure 4, the tensile and Izod impact properties, and the density of PA6 / 20 wt.% WF / 20 wt.% GF hybrid composite, are more important compared to the neat PA6 and equals to PA6 / 30 wt.% GF commercial reference. These commercial-equivalent performances of PA6 biocomposite hybrid go along with a weight reduction of around 15 % and an estimated cost reduction of around 28 % (i.e. 4.25 $/kg compared at 5.9 $/kg).

ABS / 20 wt.% WF / 20 wt.% GF mechanical properties are presented in Figure 5. They are similar or higher those of the commercial grade ABS / 30 wt.% GF, i.e. 51.4 MPa vs. 38 MPa in terms of tensile strength, 9.3 GPa vs. 6.3 GPa in terms of tensile modulus and, 3.6 kJ/m^2 vs. 4.3 kJ/m^2 in terms of impact strength. These excellent mechanical performances come along with a 15 % lower density (1.41 g/cm^3 vs. 1.65 g/cm^3) and a 15 % lower cost (3.6 $/kg vs. 4.3 $/kg) comparing to the ABS / 30 wt.% GF commercial grade. Therefore, our current set of experiments and data seems to indicate that the partial replacement of GF reinforcements in PA6 and ABS composites by cellulosic fibers led to hybrids having at least equivalent mechanical performances as commercial grades while having around 15 % density and cost reductions and 20 wt.% renewable (or bio-based) contents.

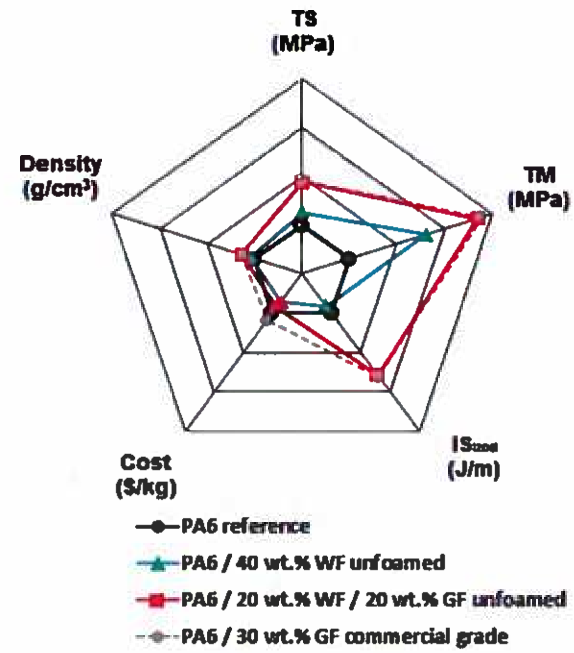

Figure 4. Comparison of mechanical properties, cost and density of: neat PA6, PA6 biocomposites and hybrids from this work, and the commercial grade PA6 / 30 wt.% GF.

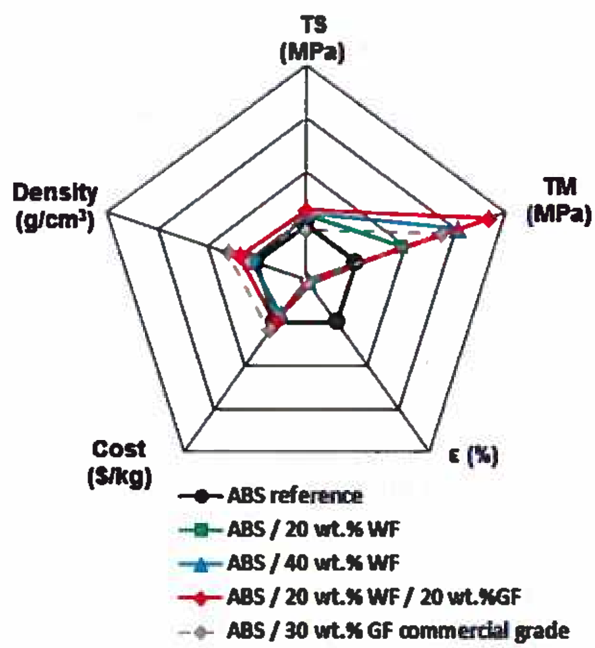

Figure 5. Comparison of mechanical properties, density and cost of: neat ABS, ABS biocomposites and hybrids from this work, and the commercial grade ABS / 30 wt.% GF.

Process strategy: lightweighting by injection foaming

During the injection foaming, a chemical or physical blowing agent is injected into the polymer melt initiating the formation of a single phase (polymer / gas solution) which will expand after injection into the mold cavity. This process leads to the formation of a structure with foamed core and compact layer as skins. The thickness of the core and skins depend on polymer type, additives used, type of blowing agent and parameters used during the injection molding (melt temperature, mold temperature, cooling time, injection speed etc.). The most important advantage of the foaming in injection molding is the reduction of the weight of the final injected part.

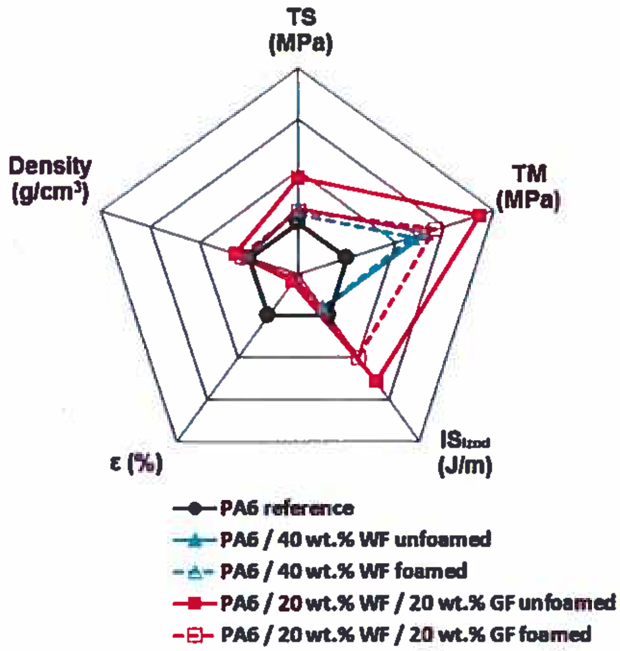

Figure 6. Properties comparison of: neat PA6, unfoamed / foamed PA6 / 40 wt.% biocomposites and unfoamed / foamed corresponding hybrid.

In this work, biocomposites containing 20 wt.% and 40 wt.% of cellulosic fibers and hybrids containing 20 wt.% cellulosics / 20 wt.% GF based on PA6 and ABS were foamed in injection molding process using 2 wt.% of Hydrocerol 1514 as chemical blowing agent. These biocomposites were foamed in rectangular parts (for Izod impact tests) and dogbones (for tensile tests) with dimensions as defined in the ASTM D256 and the ASTM D638 respectively. Figure 6 shows a comparison of properties of unfoamed and foamed PA6 / 40 wt.% WF and PA6 / 20 wt.% WF / 20 wt.% GF hybrid biocomposites. The PA6 / 40 wt.% WF presented a decrease of around 8 % in mechanical properties after injection-foaming. The tensile strength decreased from 79 to 72 MPa, the tensile modulus from 6400 to 5700 MPa but the Izod impact strength remained unchanged at 17 J/m. The density of the unfoamed PA6 / 40 wt.% WF material (1.23 g/cm^3) decreased by 10 % after foaming (1.11 g/cm^3). On the other hand, PA6 hybrid biocomposites displayed a drop of 20 % from 57 to 47 MPa of the tensile strength, of 10 % from 7600 to 6800 MPa of the tensile modulus and of 15 % from 34 to 29 J/m of the impact strength. The density of the hybrid PA6 / 20 wt.% WF / 20 wt.% GF (1.46 g/cm^3) diminished by around 10 % (1.3 g/cm^3). The foamed PA6 biocomposites presented a 10 % weight reduction and 10-20

% reduction in mechanical properties compared to unfoamed biocomposites. Despite of that, the properties remain very interesting for automotive applications.

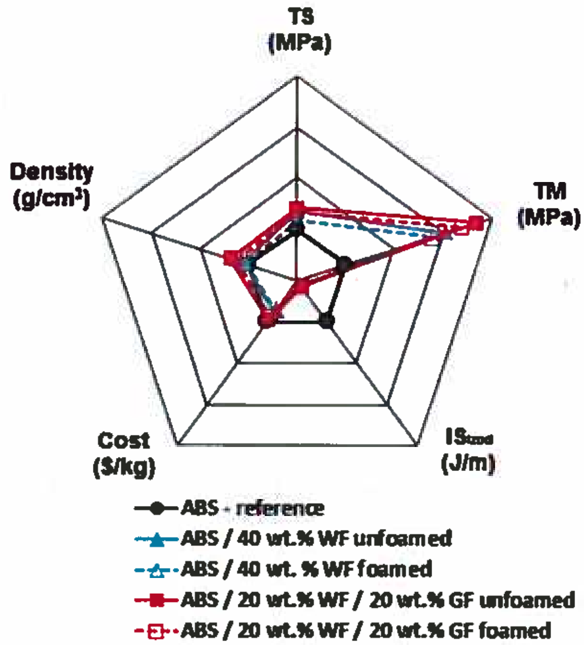

Figure 7. Properties comparison of neat ABS, unfoamed / foamed ABS / 40 wt.% biocomposites and unfoamed / foamed corresponding hybrid.

Figure 7 shows the mechanical properties, projected costs and densities of ABS / 40 wt.% WF and ABS / 20 wt.% WF / 20 wt.% GF hybrid, before and after injection-foaming. ABS / 40 wt.% WF has lost around 10 % in tensile strength (from 51 to 45 MPa) and tensile modulus (from 7700 to 7000 MPa) after the injection-foaming while the impact strength remained unchanged (21 J/m). The hybrid ABS / 20 wt.% WF / 20 wt.% WF also lost 10 % in tensile strength (from 54 to 51 MPa) and tensile modulus (from 9300 to 8500 MPa) after the injection-foaming while the impact strength remained again unchanged (26 J/m). For ABS foamed biocomposite and ABS foamed hybrid, the density and cost reductions compared at the unfoamed counterparts were around 6-8 %. Nevertheless, the ABS biocomposites and ABS biocomposite hybrids remain performant materials with projected cost reduction of about 25 %. The performances of foamed PA6 and ABS biocomposites seem to demonstrate that the injection-foaming process is an efficient and rapid solution to reduce weight and cost of automotive plastic parts.

3.4 Greener bioblends and biocomposites based on PA6 and ABS

The substitution of a part of PA6 and ABS matrix by a bioplastic was used as strategy to promote their renewable content. In this work, PLA was used to replace 10 - 20 wt.% from the engineering thermoplastic matrix and produce PA6 / 20 wt.% PLA and ABS / 10 wt.% PLA bioblends that were further reinforced with cellulosic fibers to obtain PA6 / 20 wt.% PLA / 20 wt.% WF and ABS / 10 wt.% PLA / 20 wt.% WF biocomposites respectively.

The mechanical and thermal properties of neat PA6, PA6 / 20 wt.% PLA bioblend, their biocomposites containing 20 wt.% WF and the commercial grade PA6 / 30 wt.% minerals are presented in the Figure 8a. The PA6 / 20 wt.% PLA presented very similar mechanical performances as neat PA6. The corresponding biocomposites, PA6 / 20 wt.% WF and PA6 / 20 wt.% PLA / 20 wt.% WF, were similar to the commercial reference from a point of view of the mechanical performance. In terms of thermal resistance, the HDT of PA6 / 20 wt.% PLA (103 °C) dropped as expected compared to neat PA6 (160 °C) due to the well-known low thermal resistance of PLA (around 55 °C). Even so, owing to cellulosic fibers addition, the PA6 and PA6 / PLA biocomposites presented a significant enhancement in HDT values, i.e., up to 170 °C and 188 °C respectively. These values remained slightly lower than the one of the commercial reference, i.e. 195 °C. Concerning the impact strength, as mentioned before, the biocomposites developed in this work were not formulated to perform under impact, so the IS_{Izod} values presented in the Figure 8a are 50-70 % lower than for the commercial reference. For that reason, we recommend to add impact additives when formulating these biomaterials to further enhance their impact response. Overall, the PA6 / PLA bioblends and biocomposites can be formulated to contain up to 40 wt.% renewable content while presenting very encouraging performances for automotive interior applications. Furthermore, PA6 bioblends and biocomposites can be easily adapted to injection and injection-foaming processes without modifications of the process. Figure 8b shows an image of injected parts based on neat PA6, PA6 / PLA blend and on PA6 / PLA biocomposite fabricated in our semi-industrial scale laboratory by injection molding.

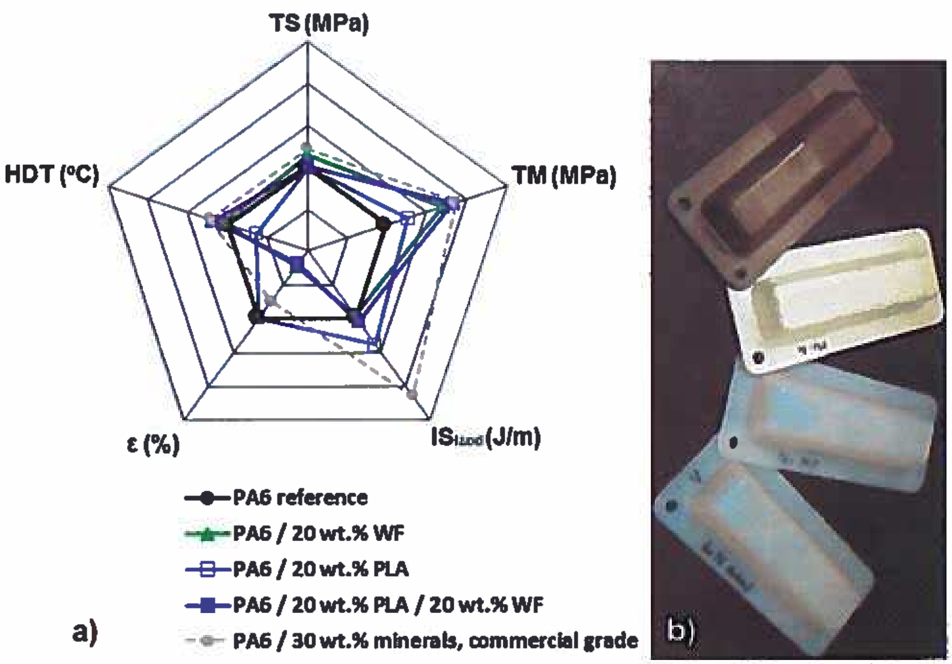

Figure 8. a) Properties comparison of PA6, PA6 bioblend and biocomposite from this work and the commercial grade of PA6 / 30 wt.% minerals and b) Injection molded samples based on PA6, PA6 / PLA and biocomposite

Examining the Figure 9a, similar observations can be made for ABS / 10 wt.% PLA bioblend and its biocomposite with 20 wt.% WF. The properties of ABS / 10 wt.% PLA were at least equal to neat ABS (i.e., TS about 42 MPa, TM about 2500 MPa, ε about 20 %, and HDT about 85-90 °C). On the other hand, the properties of ABS / 10 wt.% PLA / 20 wt.% WF biocomposite were at least equivalent to ABS / 20 wt.% WF biocomposites (i.e., TS about 50 MPa, TM about 4500 MPa, ε about 2.5 %, and HDT about 90-92 °C). In terms of Izod impact strength, it is well known that ABS materials are dedicated to the production of impact resistant parts for automotive interior application. For this reason, we recommend to add impact additives at this biomaterial formulation to further enhance its impact response. Therefore, the ABS / PLA bioblends and biocomposites can be formulated to contain at least 30 wt.% of renewable content while presenting good potential for automotive interior applications. As for PA6 bioblends and biocomposites, the ABS biomaterials can also be adapted to injection and injection-foaming processes without bringing important changes to the process and to the properties. Figure 9b shows injected parts based on neat ABS, ABS / PLA bioplastic and on ABS / PLA biocomposite fabricated in our laboratory by injection molding process.

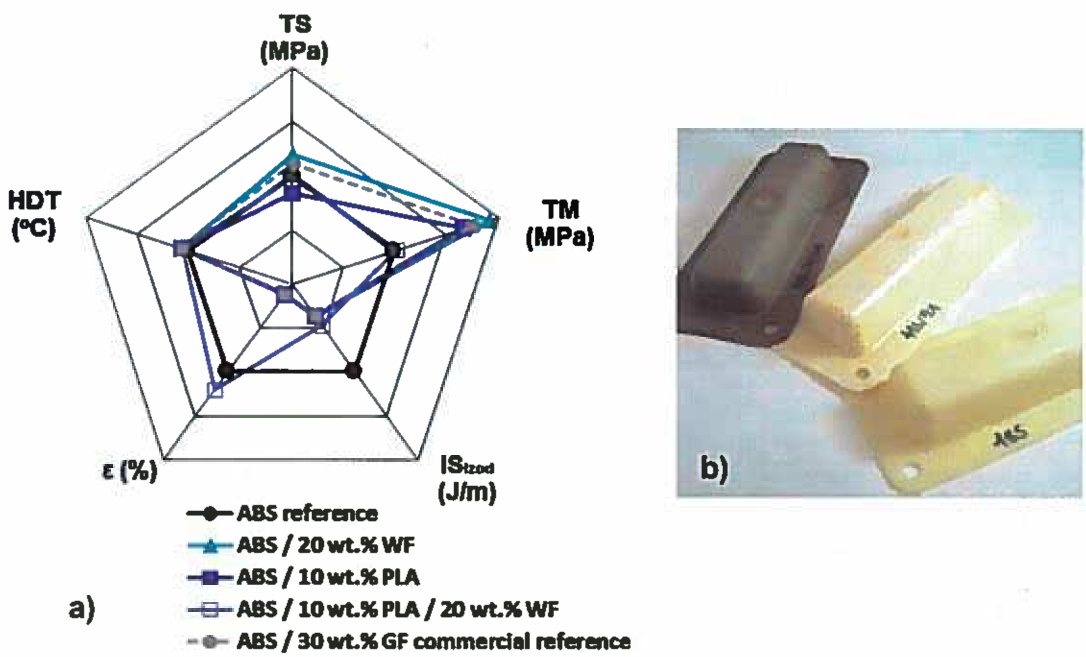

Figure 9. a) Properties comparison of: neat ABS, ABS bioblend and biocomposite obtained in this work and ABS / 30 wt.% GF as commercial reference and b) Injection molded samples of ABS bioblend and biocomposite

4 CONCLUSIONS

This paper presented strategies towards lighter, lower-cost and sustainable PA6 and ABS polymer products having high potential for use in automotive interior parts. Biocomposites containing up to 40 wt.% cellulosic fibers based PA6 and PA6 / PLA, ABS and ABS / PLA presented equivalent or higher mechanical and thermal properties compared to conventional engineering thermoplastic compounds and to commercial composites currently used in automotive applications, while having:

- Up to 37 % lower-cost due to the incorporation of up to 40 wt.% of cellulosic fibers;
- Up to 10 % lower-weight due to the partial or complete replacement of glass fibers by cellulosic fibers and/or by using an adequate injection foaming process;
- Up to 40 % renewable content when, besides cellulosic fibers, a bio-based polymer is used in a bioblend with the engineering thermoplastic.

This work proved the feasibility of the novel PA6 and ABS bioblends and biocomposites as eco-solutions for automotive applications. The lower-cost, lower-weight and the greener content are capital characteristics of these biomaterials. Although impact properties, moisture sensitivity and odor still need to be improved, those bioblends and biocomposites enable designing engineering thermoplastic compounds containing up to 40 wt.% renewable content.

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